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THE EFFECTIVENESS OF FOREST FIRE-FIGHTING FOAMS

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Fire Suppression Systems

Suppression of forest fires is dependent on breaking at least one of the links in the fire triangle, i.e., isolating one of air, fuel, or heat from the other two. Water has been used extensively to attain this goal and in more recent times retardants have played a major role in aerial suppression. The need to apply copious quantities of water has been the driving force in the search to enhance water's suppression capabilities. Currently, the answer seems to lie with using a foaming agent. The conversion of water from a liquid to a bubble state imparts new characteristics to the water and results in superior suppression qualities. The foam affects all three sides of the triangle and produces side benefits that are an aid to suppression. A particular function performed by the foam will, in some instances, modify more than one of the fire parameters, thereby compounding the net benefit.

The least complicated relationship is that between the foam and air. The viscosity of water is such that very little adheres to the surface on which it lands. It drains off immediately and only a miniscule amount is retained if this surface is not very rough or porous. Foam is semifluid in most cases; consequently, gravitational forces are able to set up a gradual flow after it comes to rest. The result is that more water adheres and remains on site for a much longer period of time when in the foam state. During this interval, the foam acts as a durable barrier and excludes the oxygen-enriched air from the fuel's surface. Vaporized water is trapped at the fuel's interface by the foam layer and air pockets in the fuel's proximity attain high relative humidities. Foam impedes the free movement of air; consequently, moisture-laden air is not replaced by dry air. When water is applied to live coals, the skin-thin layer of water that adheres is readily evaporated and oxygen-enriched air is permitted to enter and foster combustion. When this same volume of water is expanded 10 times, the resulting foam layer forms a deeper protective envelope.

The heat segment of the tripartite making up the fire triangle is severed by foam in several ways. The brilliance of the foam blanket reflects some of the energy that impinges on it and it absorbs the balance. The sphere-like structure of the bubbles causes incoming energy to dissipate laterally and localized preheating is minimized. The pathway through the bubble mass is made up of the fluid in and around the bubble skins and the air within these bubbles. These air cells act as pockets of insulation; as a consequence, radiant energy becomes highly diffused when it enters the foam. The energy that is absorbed is used to evaporate water trapped in the foam structure. The net result is slower evaporation per unit of surface area and an overall delay in the exposure of the fuel's surface to oxygen and heat. The foam physically insulates the burning fuel from the surrounding environment and starves the burning fuel of oxygen. Cooling takes place as the energy released at the combustion interface is dissipated. The potential for rekindling is reduced and rekindling only takes place where the energy output exceeds that needed to totally dissipate the foam cover.

The fuel segment of the fire triangle is affected by foam in diverse ways. A heavy application of foam does not drain off instantaneously like water, but flows gradually and envelops the fuel particles on which it lands; consequently, much more water is held in the bubble structure per unit of fuel surface. This increase in amount means that there is more available water for wetting and for absorbing heat. The surface-active agent in foam reduces the surface tension of the solution from approximately 72 mN/m to less than 33 mN/m. At this level, the liquid's molecular bond is released sufficiently to enhance the water's ability to spread, to wet, and to penetrate porous materials. Because foam comes to rest where it lands, it releases its liquid component at a regulated rate and wetting of the fuel is achieved much more efficiently. Hard-to-wet surfaces, which shed water, will be coated by foam

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and as it adheres, it wets with the aid of the wetting agent. Vertical surfaces are also difficult to wet with water even if they are receptive to water, but, when in the foam state, a substantially greater amount of water can be entrapped and rendered available for wetting and heat absorption. The rigidity and life of the bubble structure depend on bubble uniformity, mix percentage, exposure to sunlight and wind, and the efficiency of the foam generator. In field applications, the descent path of foam is altered by air resistance and air movements much more so than that for water. The end result is that foam penetrates through openings to envelop fuels that might otherwise not be wetted. This enveloping of fuels results in isolating volatiles emanating from the fuel particles or, at least, diluting these volatile substances to a point where the ignition threshold is greatly altered. The controlled rate of breakdown of the foam rate not only enhances wetting but also modifies the microclimate within the fuel complex. Within a timber stand, this escape of liquid sets up a drizzle-like condition.

Laboratory Test Fire Results

The use of prescribed burn sites for foam effectiveness evaluation is a slow method of data acquisition because of the distribution and availability of suitable burning days. To supplement field data that were already available and data that would be collected from future burns, laboratory test fires were initiated to determine the relative superiority of foam compared with water. The indirect suppression mode (pretreatment) was used to determine the application levels required to control fire spreading in slash fuels burning at different intensity levels. Under laboratory no-wind conditions, fire intensity was changed by increasing the fuel loading. The maximum attainable intensity was equivalent to that of a light wildland burn.

Two types of fuel were used: needleless white spruce branches with stem diameters of less than 1.5 cm; and balsam fir branches with all of their needles intact. The required quantity of air-dry fuel was manually spread uniformly over the entire surface of the bed (1.5 m x 3.0 m) to ensure that fuel depth and loading density were reasonably consistent.

An overhead mobile spray ring was used to apply the suppressants (water or foam). Half of the fuel bed was covered prior to suppressant application and the specified level was applied to the exposed fuel. Once the bed was uncovered and positioned under the exhaust hood, the exposed end of the untreated fuel was ignited. The times of the fire's arrival at each successive station (station spacing of 0.5 m) and the time the fire went out upon reaching the treated fuels or after penetrating through any part of the treated zone were recorded. The burned portion of the bed was sketched to scale at intervals as the fire progressed.

The application level for each test was recorded and the fire intensity was calculated after the appropriate fuel moisture adjustment was made. The rate-of-spread (ROS) in the untreated fuel and the ROS reduction for those fires that burned through the full length of the bed when the application level was insufficient were calculated. The intensity of each burn was calculated using Byram's equation

$$I = HWR$$

Parallel tests were conducted using water and foam. Amounts required to stop the fire from burning through the treated zone were plotted.

White Spruce Slash Tests

Water drained down to the bottom of the fuel bed; therefore, only a portion of the applied volume protected the fuel particles from immediate ignition. Foam remained where it was applied, flowing gradually to encapsulate the fuel particles, thereby facilitating the suspension of a greater amount of water on the fuel surfaces. The foam's insulating and barrier-building characteristics resulted in a 30% reduction in application requirements relative to water (Figure 1). The variation in effectiveness between foam brands (Silv-ex and Chemonics #103) was not significantly different. The foam generated by the spray rig system had an expansion in the five to six times range and its drainage rate (Figure 2) was slow. This ensured that a reasonable quantity of foam remained on the fuel when the fire arrived some 4-7 min after the foam was applied.

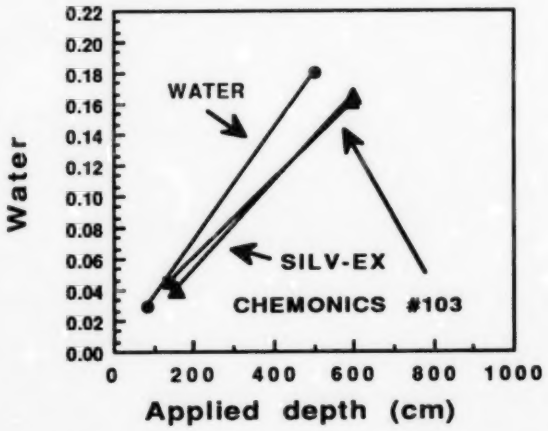

Figure 1. Minimum application levels of water, SILV-EX foam, and CHEMONICS #103 required to suppress white spruce slash laboratory burns (foam application level given in terms of depth of solution used in generating the foam blanket).

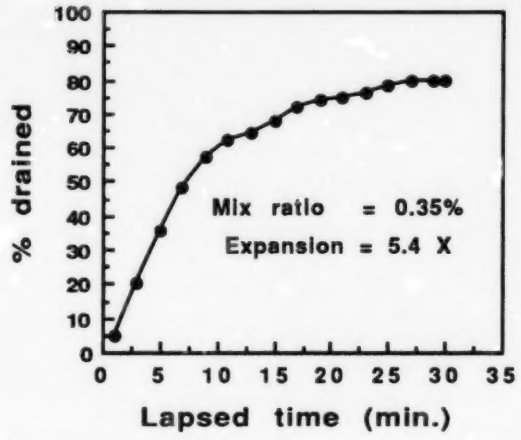

Figure 2. CHEMONICS #103 foam drainage rate.

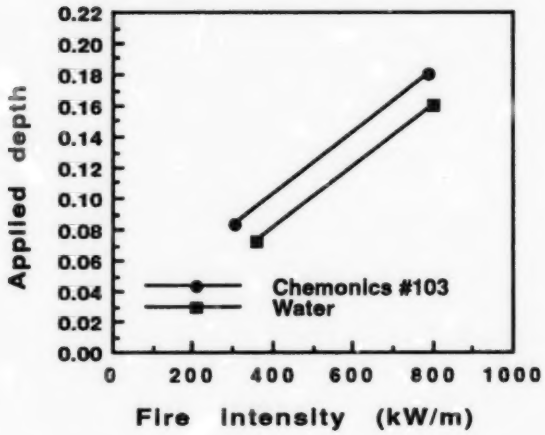

Figure 3. Minimum application levels of water and CHEMONICS #103 foam required to suppress balsam fir slash laboratory burns (foam application level given in terms of depth of solution).

Balsam Fir Slash Tests

The balsam fir branches had all of their needles intact; consequently, the slash formed a continuous mat of fuel. Water applied to the upper surface percolated through to the bottom and afforded some wetting at all levels, but the foam formed a cohesive blanket across the top of the fuel bed and provided slow progressive wetting of lower levels within the bed as it drained. The amount of liquid available for wetting was restricted due to slow drainage (Figure 2). As a result, the foam was not as effective as the water for fires in this particular fuel structure (Figure 3). The intensity range for this test series was from 300 kW/m to 800 kW/m and the application difference between water and foam remained constant at 0.021 cm. This difference in the amount applied would narrow or even disappear if more rapidly draining foams were used because wetting would be initiated immediately after the foam came to rest on the surface of the fuel mat and its behaviour would be water-like except for its surfactant qualities.

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